Case Study

IR-SIP Project Data[1,2]

The Atmospheric Analyzer (AA) satellite (see Figure 1) is an Earth-observing satellite in the NASA Small Explorer Program. The Mission is limited to 60 Million dollars including the launch vehicle and is scheduled to launch 36 months after contract award by NASA HQ. The purpose of the mission is to advance the state of the art in detectors and will use all new technology in the Infrared Sensor Instrument, which is the primary instrument on the observatory. The other two instruments are instruments of opportunity and are not necessary for mission success. The observatory will collect data for modeling the Earth's atmosphere from sea level to the edge of space (80,000 meters). It is expected to remain in operation for 3 years. Operations will include checkout and calibration of instruments upon reaching stable orbit and then routine scientific operations. Routine operations will include the ability to reprogram the software in order to correct detected problems.

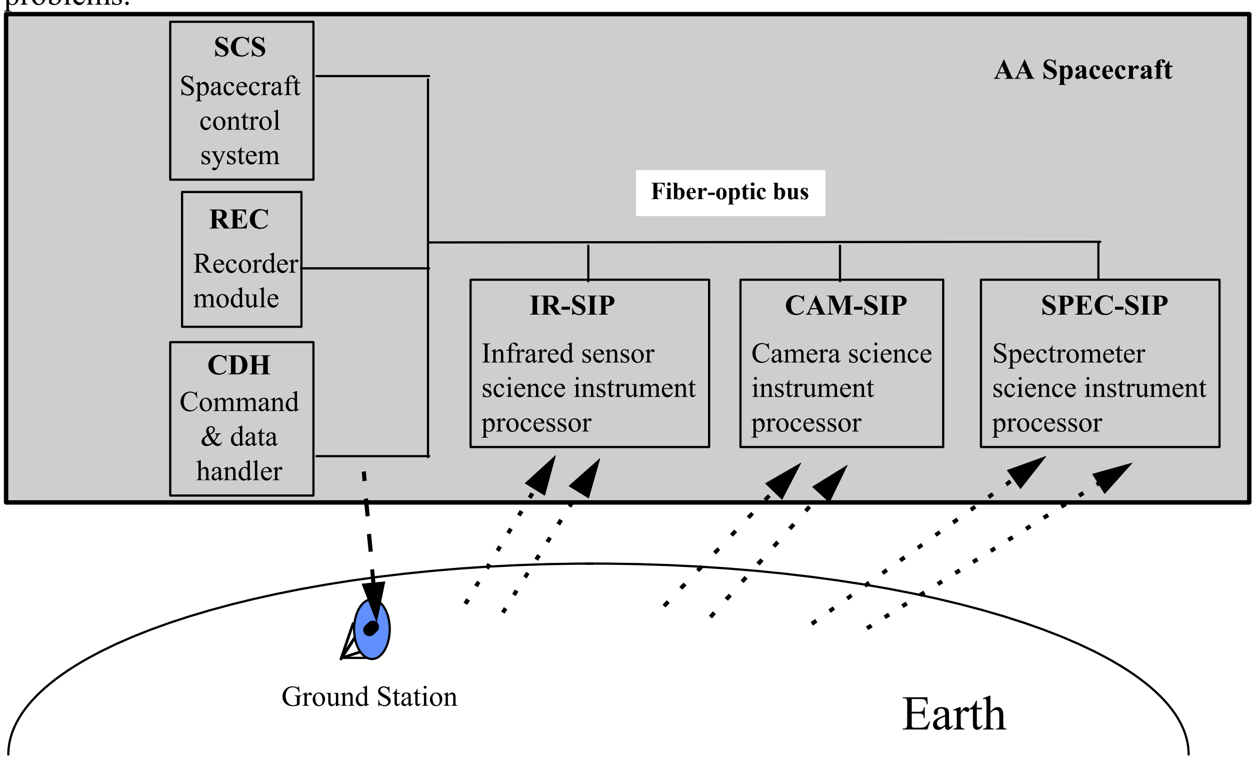


Figure 1. AA Spacecraft Hardware Architecture

[1] This case study is built and synthesized from a variety of projects and experiences, both with NASA and some relevant industry projects. It is designed as a teaching aid to support specific points in this class. Any resemblance to a specific project, either in whole or in specific details, is unintentional.
[2] This case study embodies both textual and graphical work created by the U.S. Government and forms/templates/tools copyrighted by Carnegie Mellon University (CMU), published in the *Continuous Risk Management Guidebook* (copyright 1996 by CMU).

The Atmospheric Analyzer will incorporate the data measurements from three separate instruments. These instruments are:

1. an ***infrared sensor instrument***, which is used to measure the heating and cooling of the Earth's atmosphere

2. a ***digital camera instrument***, which is used to observe cloud formations and storm systems

3. a ***spectrometer instrument***, which is used to analyze the chemical composition of the atmosphere

Operations Description

The infrared data are correlated with solar activity data provided from outside the AA project. In normal science operations mode, the data are collected every 0.25 seconds from the instrument.

To reduce operations cost, the AA satellite is required to run as autonomously as possible from ground control, so that the ground control center would not need to be staffed continuously. This means that the satellite needs to recognize the need to maneuver based on rules it retains and on information provided by spacecraft operators. It will also need to recognize when the ground station is within range so that it can transmit the data to be downlinked. There will be a single ground station dedicated to this satellite only, through which all spacecraft/ground links are made. The nominal operational scenario calls for one science data downlink per day. The satellite is in contact with the ground through a schedule of contacts ranging from 5 to 20 minutes. There are 15 orbits per day.

When science data are downlinked, the ground system executes a verification program that analyzes the data to verify that the transmission packets are free from errors, and checks time tags to determine if any packets were missed. If an excessive amount of data is lost, an operator is notified (via beeper) so that he or she can determine the reason, and if necessary command a retransmission during the next orbital pass.

Since a large amount of data needs to be stored on board, each of the science instruments has its own CPU and software associated with it. This software controls the instrument and does initial processing such as limit checking, and filtering or averaging the data and compressing it.

The spacecraft also downlinks data about the other spacecraft systems. Basic data regarding its health and status are downlinked during each pass. The ground station software will unpack and analyze the data, and will send an alert to an operator's beeper if a problem is detected. Otherwise, the ground system also operates autonomously. The main activity of the operators are to formulate spacecraft orbit adjustment maneuver commands to be uplinked to the Spacecraft Control System (SCS) based on requests from the scientists. The scientists base their requests on analysis of the downlinked data. If an anomaly occurs on the observatory that violates mission constraints, the observatory will automatically be placed in safehold. While in safehold, all transmissions are terminated to save power. The failure to downlink data is the only notification that the ground station receives that there has been an anomaly. The observatory can survive for 15 hours in safehold before the batteries discharge and the observatory loses the capability to recover normal operations. Normal operations can only be restored by specific manual commands sent to restart the observatory by the ground controller.

Engineering Considerations

The need for autonomy and high data rates has led to the following system engineering decisions:

1. The flight software will run on multiple processors with one CPU for each science instrument. This will be done so that science data collection will not interfere with guidance, navigation, and control computations.

2. A new high-speed fiber-optic data bus will be used so that high data transfer rates can be sustained.

3. A solid state recorder with at least 20% reserve capacity above one day's science data is the minimal requirement. This will allow three further attempts to retransmit data before any data are lost through overwriting. The alternative is to have redundant recorders. This decision will be made based on a reliability analysis for these recorders.

AA Flight Hardware Architecture Description

The components of the AA Flight Hardware (which can also be seen in Figure 1) are as follows:

Spacecraft Control System (SCS) -- This subsystem manages all the hardware used to operate the spacecraft, and performs computations needed to support the operation of the spacecraft. The two most important SCS capabilities are flight dynamics (i.e., maneuvers) and power management. Typical flight dynamics hardware includes gyroscopes, sun sensors, a Global Positioning System receiver, and thruster motors which are used to determine the position of the spacecraft and perform maneuvers. Power management involves the movement of solar panels to maximize the sunlight converted to electricity, the charging of batteries from the solar panels, and the consumption of power by all components of the spacecraft system.

Command and Data Handler (CDH) -- This subsystem controls the communications between the spacecraft and the ground station. This includes pointing the high gain antenna towards the ground station, building downlink transmissions from recorded data, unpacking uplinked commands, and sending commands to the correct subsystem.

Science Instrument Processors (SIP) -- As discussed above, there is one CPU for each science instrument. That is, the software for each instrument is unique to that instrument, and thus is developed as a separate Computer Software Configuration Item. The subsystems associated with the infrared sensor, the digital camera, and the spectrometer are called IR-SIP, CAM-SIP, and SPEC-SIP, respectively.

Recorder Module (REC)-- This subsystem provides an interface to the spacecraft's solid state recorders. Data to be downlinked are written to the recorder interface by the SCS and SIP subsystems, and are played back to the Command and Data Handler (CDH) subsystem upon request so that the CDH can transmit the data to the ground station.

Fiber-optic Bus -- The data passed between subsystems are all placed in packets and broadcast on the fiberoptic bus. Each subsystem is responsible for recognizing what packets it needs to read under what conditions. For example, the Recorder Module (REC) is required to recognize packets sent from the various Science Instrument Processors (SIPs) and record them.

Case Study

IR-SIP Project Data (continued)

Work Breakdown Structure

The work breakdown structure and the current project schedule are provided below. Review this information and then try to answer the questions in the Brainstorming Exercise handout. Use your own experiences and background to think about the overall picture being presented by this project data.

AA Satellite Work Breakdown Structure (WBS)

Atmospheric Analyzer (AA)
- Project Management
- Systems Engineering
- Subsystems
  - CI 1, Control Center
  - CI 2, Spacecraft Control System (SCS)
  - CI 3, Command & Data Handler (CDH)
  - CI 4, Recorder Module (REC)
  - CI 5, Infrared - Science Instrument Processor (IR-SIP)
  - CI 6, Digital Camera - Science Instrument Processor (CAM-SIP)
  - CI 7, Spectrometer - Science Instrument Processor (SPEC-SIP)
- Site Activation (Installation, etc.)
- Test & Evaluation
- Training
- Operations and Maintenance
- Data
  - Publications

CI 5, Infrared - Science Instrument Processor (IR-SIP) Work Breakdown Structure (WBS)

CI 5, Infrared - Science Instrument Processor (IR- SIP)
Project Management Plan
Project Configuration Management Plan
Project Integration Test Plan
Project Integration Test Procedures
Project Assurance Plan
Project Reviews
HWCI 5.1 Hardware
- Hardware Management Plan
- Hardware Configuration Management Plan
- HWCI 5.1.1 Infrared Sensors (n identical sensors)
- HWCI 5.1.2 Power Supply

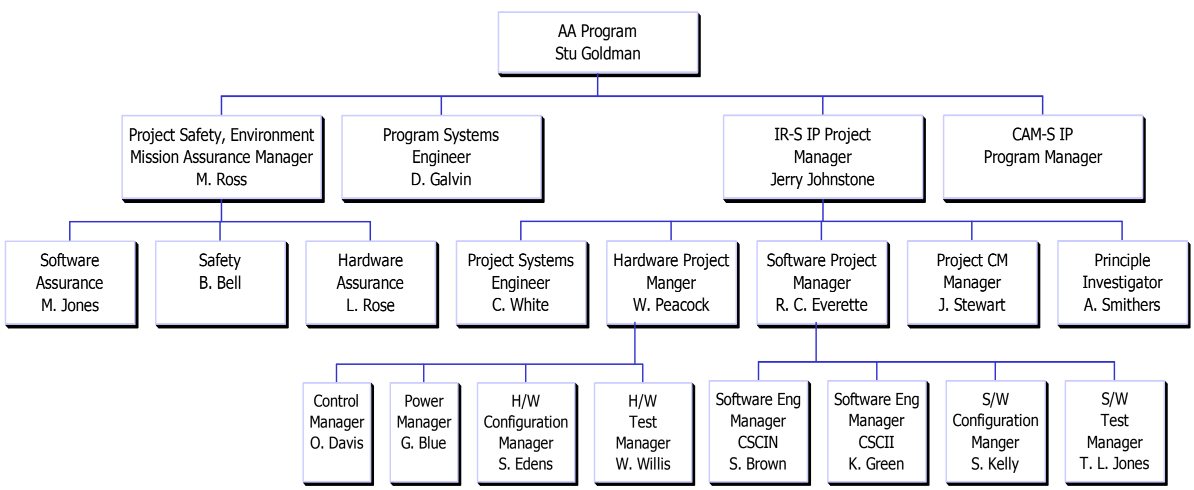
HWCI 5.1.3 Processor
HWCI 5.1.4 Propulsion
HWCI 5.1.5 Attitude Control
...

CSCI 5.2 Software
Software Management Plan
Software Configuration Management Plan
CSCI 5.2.1, Flight Software
CSCI 5.2.2, Mission Operations Software
CSCI 5.2.3, Post-Processing Software
...

2. Organization Chart

IR-SIP Project Structure

The project organization[3] for the AA/IR-SIP Project is shown in the following figure:



3. Schedule

This project is using a waterfall life cycle model. The duration and time estimates were derived from the NoBrains Estimating Tool. Jerry then revised the estimates with input from one of his former colleagues who had worked with a similar project.

Assumptions

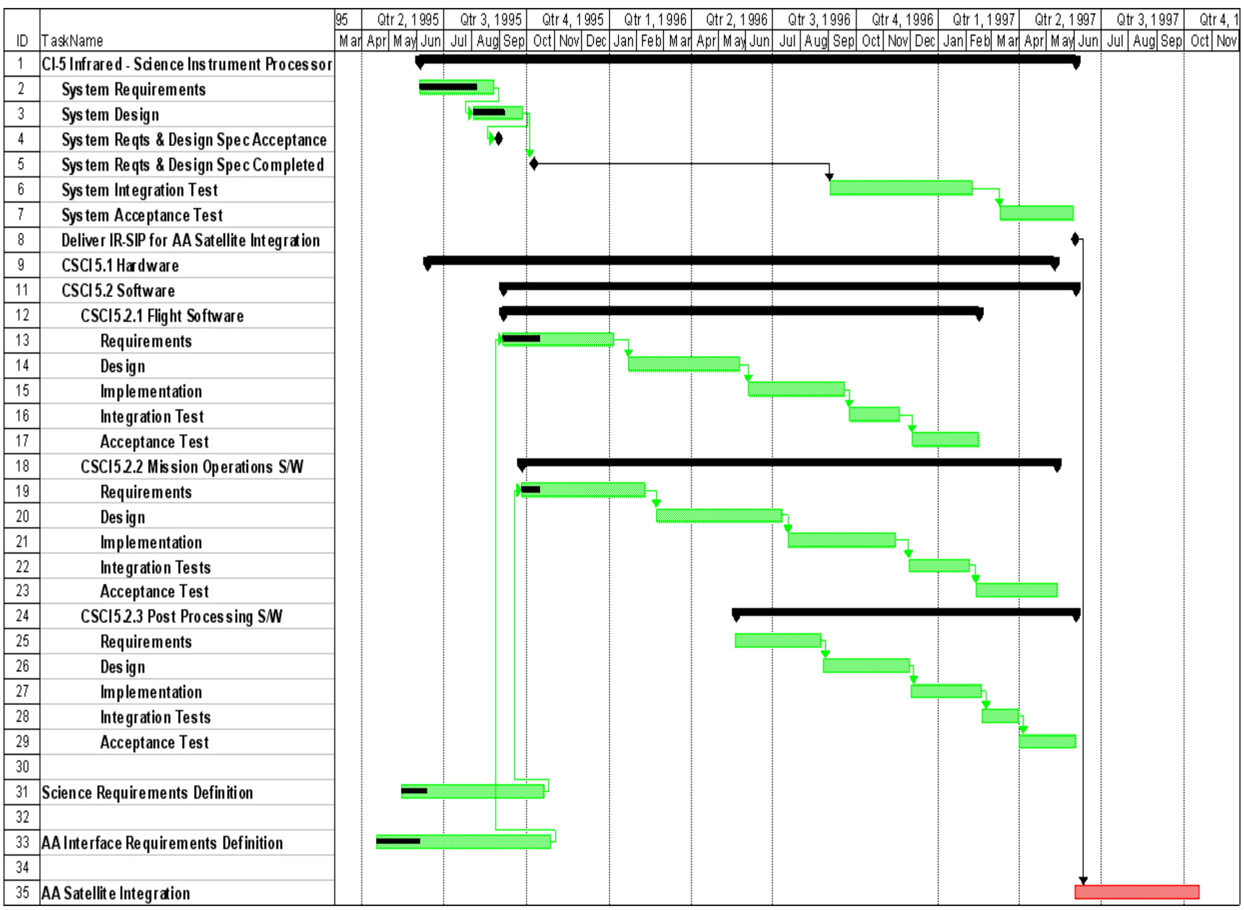
10,000 lines of code for flight software @1 Lines/Hour - uses linear constant model, instead of exponential

[3] An example organization - not intended to imply typical or optimal organization structures.

Phase	Flight S/W Duration (In Months)	Flight S/W Time From Start (In Months)
Requirements	6.0	6.0
Design	6.1	12.1
Implementation	5.3	17.4
Integration Test	2.6	20.0
Acceptance Test	3.5	23.5

The Gantt chart, showing progress to date, is below. Progress is marked by a solid bar (actual work completed) inside a shaded bar (original estimated time to complete). The current project date is marked by a heavy vertical line (10/16/95).

Hints: Look at the current project date, 10/16/95, and the progress on line items 2, 3, 13, 19, 31, and 33. Note the critical dependency of items 8 and 35.



Project Manager Comments for Review

This is the text of a conversation with Jerry Johnstone and a software engineer interested in working on the project.

I'm Jerry Johnstone, and I'm the project manager for the IR-SIP project. You've already seen the project description, so let me tell you where things are now.

I'm very excited to be the project manager for this project. This is the first system I've managed that will fly in space and I think this is going to be a very positive experience for me and the rest of the people here. All my other projects were ground-based control systems and they were all very successful. The people working for me are very good and they've done these types of projects before, but one of my goals is to streamline our development process. It's getting to be a very competitive world for funding these types of efforts and we really need to be cost-efficient.

In order to reduce mission administrative costs, I have decided to reduce project overhead by having only a secretary, a financial manager and an assistant project manger. All technical decisions will be made by me and Assistant Project manager, Stu Goldman.

Rather than using the very costly center configuration control system, I have decided to allow W. Peacock (hardware manager) and R.C. Everette (software manager) to use whatever configuration management process they are comfortable with. Each will prepare a configuration management plan and submit it to me to be incorporated into the project plan.

The software engineers working for Everette are just a fantastic bunch of folks, always willing to put in extra time to meet schedules and finding really efficient workarounds for hardware issues. In my experience, software can fix just about any problem hardware comes up with.

Our system development is based on good, solid engineering principles that apply to any project. The waterfall life cycle has always done very well by me and that's what we're using here, so I foresee no problems whatsoever.

The AA Satellite that IR-SIP will fly on has reduced its schedule, and after speaking to my team managers, we've really got to fly on that satellite. I've looked at the original schedule put together by my predecessor and he was far too pessimistic. With the current schedule, I've got us down to a lean operation with delivery four months sooner. This will get us to the integration milestone with the AA satellite.

Due to the short time to design, build, test and launch the observatory, I have decided that the hardware test program will be limited to sub assembly tests of the instrument and spacecraft and a functional test, at ambient conditions in vacuum, performed on the entire observatory prior to launch.

I have also decided to use commercial grade parts in the spacecraft and instrument because they have worked well in ground system projects, are more readily available, and are less expensive than space qualified parts. Besides, many of the space qualified parts have procurement lead times of 18 months or more.

We're now in the requirements definition stage of the flight software. Things are going marvelously. Now I know that the AA Program is a little late in defining some of the interface requirements, and that's causing us to slip a bit, but we can work around that. We're waiting for the AA interface requirements to be solid before we design our software so we've got plenty of time. And besides, we'll be able to upload changes to the flight software during operations anytime we need to fix anything so if we miss anything, it's not a disaster.

Now one of the most exciting opportunities on IR-SIP is that we're only the second project at this center to use object oriented design and the C++ programming language. Every single one of our software people has the chance to learn something new on this project. This will put our software engineers on the forefront of the technology curve and really bring us into the future. And we've selected one of the newest compilers with all the latest features to help us improve our efficiency.

The experiments we're going to be able to do with this new infrared system will be fantastic. The scientists are quite enthusiastic about coming up with more experiments they can do with it. We've actually got more experimenters signed on than were originally expected so we'll be able to make total use of all our operations time.

So, what do you think about our project?

ID	Risk	Context
1	This is the first time that the software staff will use OOD; The staff may have a lower-than-expected productivity rate and schedules may slip because of the associated learning curve.	Object oriented development is a very different approach that requires special training. There will be a learning curve until the staff is up to speed. The time and resources must be built in for this or the schedule and budget will overrun.
2	Commercial parts suitability for space applications is unknown; parts failure may lead to system failure and use of space grade parts may cause schedule delays since space qualified parts procurement have a procurement lead time of at least 18 months.	Although commercial parts are more readily available and less expensive, they have not been subjected to conditions in space. Radiation environments can cause the failure of non radiation hardened parts.
3	The high-speed fiber optic data bus is untested technology; the bus will not perform as specified and high data transfer rates will not be sustained.	Fiber optic data bus was selected because of potential for satisfying requirements for maintaining a sustained high data transfer rate. However, the technology has not been used in a space flight environment not has the technology been used to connect the particular CPUs and instruments that will be used on this satellite. Preliminary tests in a simulated environment revealed unexplained anomalies.
4	First time the IR Instrument Project manager is managing a project to go into space; Project may fail due to insufficient / poor management.	The project manager has a degree in electrical engineering and does not know much about software or how to manage it as an integral element of an overall system. He knows that the NASA handbook 7120.5 says that he should have a project plan, preliminary design etc., but he thinks that much of that is unnecessary process baggage from the past way of doing business and is non-added-value. He has bought into the 'BETTER FASTER CHEAPER' slogan and thinks that it can be achieved by cutting processes out, and by cutting out some of the early project documentation and much of the software documentation and processes to reduce cost.
5	Lack of a thorough hardware test program; mission failure due to environmental conditions not tested.	Failure to test hardware parts to the temperature extremes in vacuum could lead to unknown problems surfacing on orbit as the spacecraft experiences thermal variations.
6	Project software schedule and resources were underestimated; Schedule slips, cost overruns, and a reduction in adequate testing time are likely results.	Estimates were made by inexperienced personnel and were based on incomplete information. "Rules of Thumb" that have been validated in similar projects suggest that both schedule and resource estimates are extremely optimistic.

ID	Risk	Context
7	Science requirements have substantial TBDs; late completion of TBDs likely, with reduction in adequate testing time, possible science application software failure, incorrect science data being captured, hardware damage if incorrect safety limits were provided, extensive rework and substantial cost overruns, mission failure if problems not found before system is in operation.	(A) Due to TBDs in the science information about the mission that have not yet been researched enough to obtain conclusions, reasonably certain science requirements are not yet available. Uncertainties in the science requirements exist in the following areas: sensor sampling rates, limit checking constants, sensor data processing algorithms, and which information will be sent to the ground under specific circumstances. (B) Not enough civil service staff or funding for contractors was available in the initial phases of the project to adequately define and document the mission requirements.
8	Mission objectives require the use of new technology in an instrument's detector circuit. The selected approach involves scaling down existing technology to operate at higher frequencies. Manufacturability and survivability of the more delicate part is unproven. Problems in either of these areas may result in schedule delay, cost overruns, or a shortened mission life.	The manufacturing process involves forming a microscopic "whisker" for use in the part. The process is essentially uncontrolled since the vendor cannot directly observe and measure the critical tapered tip of the whisker. Testing can occur on the assembled part only. Furthermore, the delicate whisker is very sensitive to handling damage, especially from electrostatic discharge (ESD). Thus, bad parts may result from poor manufacturing processes or abuse in handling the competed parts during testing and subsequent higher levels of assembly.
9	Lack of an adequate configuration management system; Inability to track parts and materials in case of GIDEP alerts.	The configuration management system selected for use on this project was based on a system previously used by the project manager. However, the pervious use did not have to accommodate the large number of dynamically changing items that must be managed in this project.
10	Yearly congressional NASA budget profiles are subject to change; this may cause the project funding profile to change each year with associated replanning, schedule impacts, labor cost increases, loss of key personnel, or project termination.	This is a typical NASA project; as such, almost every assumption that the project has made about total funding amounts and yearly funding profiles will change over the project lifetime. This includes labor costs, time and cost to replan, shifts in personnel, etc. We usually see cost overruns in terms of schedule slips, increases in labor cost to meet those schedule slips or from trying to use overtime to avoid them, constant replanning and the wasted effort and changes associated with it, and losing key personnel to other projects because we can't maintain consistent funding or have to delay work and wind up with slack time. If the overruns get to be too large in terms of either cost or schedule delays, then we face an early termination of the project by either center management or NASA HQ.

ID	Risk	Context
11	It has recently been decided that the Infrared sensors will be developed in-house and how they will communicate and how sensor data will be processed will be based on assumptions until the detailed design is baselined; the accuracy and completeness of those assumptions will determine the magnitude of change in the IR-SIP Instrument Controller CI and Infrared Sensing Unit CI interface requirements - it could be minor or catastrophic.	This is the first time these sensors will be used on a NASA mission. They will still be under design and definition during the IR-SIP Controller's software specification through implementation phases. Therefore, assumptions about the interface will have to be made in implementing the IR-SIP CSCI and if those assumptions are incorrect, then software rewrites will be necessary. We do have access to a reasonable set of assumptions and information from a contractor who has developed very similar sensors, but again, we don't really feel 100% confident in those assumptions. Problems were not anticipated in the current success-oriented schedule so there is no slack time if the impact of the changes is major. Schedule slips, cost overruns, and reduction in adequate testing time are all possible if the assumptions prove false. System testing does not begin until very late in the development, so if problems are encountered there is usually no time to make changes in the hardware. Therefore, software must provide
12	Resource availability estimates were overly optimistic- schedule shows all resources are available at the start of each WBS element; schedule slips, cost overruns and reduction in adequate testing time are likely.	Estimates were made by inexperienced personnel and were based on incomplete information. "Rules of Thumb" that have been validated in similar projects suggest that both schedule and resource estimates are extremely optimistic. In addition, availability of some of the personnel assigned to this project is contingent upon their completion of tasks on another project to which they are presently assigned.
13	Waterfall lifecycle model is being used to develop all IR-SIP software; it may cause serious integration problems between IR-SIP CI and IR sensor and/or between IR-SIP CI and AA platform leading to a missed launch window, excessive cost to meet window, or failure to successfully integrate the system.	Object oriented development was chosen, in part, because of the requirement to support reuse, concurrency and iterative development. The waterfall lifecycle model is not particularly well suited for object oriented development nor does it lend itself to reuse, concurrency and iterative development.
14	Contracting a different test facility for acoustical testing; parts may be insufficiently tested or parts may be damaged with excessive testing.	If the facility does not have properly trained personnel or the machines are older or not properly calibrated, too much power may be applied or tool little.

ID	Risk	Context
15	The funding and development schedule for the AA satellite is subject to change; IR-SIP schedule slips, cost overruns, and a reduction in adequate testing time are likely as unscheduled changes will have to be made to the software to match AA project changes.	(A) Due to TBDs in the science information about the mission that have not yet been researched enough to obtain conclusions, reasonably certain science requirements are not yet available. Uncertainties in that science requirements exist in the following areas: Sensor sampling rates, Limit checking constants, Sensor data processing algorithms, and which information will be sent to the ground under specific circumstances. (B) Not enough civil service staff or funding for contractors was available in the initial phases of the project to adequately define and document the mission requirements.
16	The C++ compiler selected for use does not come with very good user documentation, as supplied by the vendor; decreased productivity likely as software developers stumble over the same problems.	The staff is unfamiliar with both the OO development approach and the C++ development language. The poor C++ user documentation exacerbates an already difficult situation thereby placing a tremendous burden on the staff. It would be extremely surprising if staff productivity is not adversely affected.
17	This is the first time that software staff has used C++; staff may have lower-than-expected productivity rate, schedules may slip.	The staff is unfamiliar with both the OO development approach and the C++ development language. The poor C++ user documentation exacerbates an already difficult situation thereby placing a tremendous burden on the staff. It would be extremely surprising if staff productivity is not adversely affected. The time and resources must be built in for this or the schedule and budget will be overrun.
18	There is no AA Satellite Simulator currently scheduled for development; probable that the IR-SIP CSCI will fail when initially integrated with the actual AA Satellite since prior interface testing will not have been possible, thus fixes will be done very late in the project schedule and may cause the launch date to slip.	The project manager does not totally understand the necessity of the simulator, that without an AA Satellite Simulator it will be impossible to test the software prior to actual integration with the AA Satellite. Since integration will not be possible until late in the schedule there will be very little time to do corrections, and those we do have to make will be done at a high cost in staff and schedule impacts
19	Ability of new hardware to meet sampling rate timing requirements is unknown; failure to meet sample rate requirements could result in loss of science data and we may need alternative hardware or be forced to accept decreased software performance requirements.	This is the first time this processor and bus have been used by this development staff and all the specifications are not known on them yet. Manufacturer documentation is not uniform in detail concerning the hardware performance.

ID	Risk	Context
20	Subset of IR Post Processing CSCI requirements is to be satisfied with COTS products; Integration time and lifecycle costs may increase from original estimates which assumed significant saving from COTS use, leading to schedule slips and cost overruns.	COTS related savings typically occur in situations in which (A) there is a good match between the functionality required by the application and the functionality provided by the COTS and (B) the scope of functions required is contained in a single COTS or in a set of COTS that have been designed to work together. Otherwise, the cost for modifying and/or integrating COTS can approximate the cost of custom development.
21	Poor communication between the AA Project's system engineering team and the IR-SIP instrument team; substantial errors may occur in the interface between the IR instrument and the AA satellite and spacecraft integration testing may take longer than planned and consume more resources for software changes to correct the problems.	While the Fiber Optics Standard Protocol is being used, command status, and data passing is dependent upon both sender and receiver looking in the same places in the packets for the same information. Definition of message passing between the IR Instrument and the AA Spacecraft, for commands, status, and data, is incomplete and partially erroneous. Changes made by one party or the other, based on engineering necessity, are not (completely or correctly) communicated to the other party and agreement reached.
100	Project resources (personnel number and availability) and schedules were underestimated; schedule slips, cost overruns, reduction in adequacy of development processes (especially testing time adequacy) likely.	Estimates were made by inexperienced personnel and were based on incomplete information. "Rules of Thumb" that have been validated in similar projects suggest that both schedule and resource estimates are extremely optimistic. The time and resources must be built in for this or the schedule and budget will be overrun.
101	Use of C++, the selected compiler, and OOD are new for software staff; decreased productivity due to unexpected learning curves may cause coding schedule to slip.	The staff is unfamiliar with both the OO development approach and the C++ development language. The poor C++ user documentation exacerbates an already tremendous burden on the staff. It would be extremely surprising if the staff's productivity is not adversely affected. The time and resources must be built in for this or the schedule and budget will be overrun.